

A comparative study of simulation results between PHERB, ADVISOR and AUTONOMIE models

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Article Info

Article history:

Received Jun 26, 2020

Revised Feb 17, 2021

Accepted Mar 13, 2021

Keywords:

Electric vehicles

Emissions

Energy management strategy

fuel economy

Hybrid electric vehicles

ABSTRACT

In this research, a new model development and innovation of conventional boat named plug-in hybrid electric recreational boat (PHERB) was introduced to overcome the fuel economy nowadays. This paper focus on the comparison simulation results of PHERB with advanced vehicle simulator (ADVISOR) and an automotive simulation and analysis tool (AUTONOMIE) models in terms of electric machine, energy system storage, propeller and boat model. The model of the PHERB is consequent and applied mathematically in the MATLAB/Simulink environment to study its functioning performance. Besides that, fuel economy and emissions of PHERB, ADVISOR and AUTONOMIE model are equated and the pros and cons were discussed in this paper based on simulation result.

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1. INTRODUCTION

Malaysia is a promptly emerging country in Southeast Asia that aims to achieve high-income country status by 2050; its economic growth is highly dependent on fuel consumption. The conventional boat (CB) is used only internal combustion engine (ICE) to power the boat. Figure 1 Figure 2 and Figure 3 display the powertrain diagrams block for a CB, plug-in hybrid electric boat (PHEB) and the proposed plug-in hybrid electric recreational boat (PHERB). These block diagrams consist of ICE, electric machine (EM), and energy system storage (ESS) [1], [2]. The PHEB has motor and generator in EM, and an ESS without ultracapacitor (UC) [3]-[8]. Along these lines, PHERB was proposed in this work for cost sparing which one EM was work as either an engine or generator at any given moment. In ESS, there is battery and UC bank for quick charging and releasing amid the regenerative braking and quick increasing speed. The ICE is required when the condition of charge (SOC) of the ESS is low, then ICE only mode is activated. The ICE in PHERB can drive the boat while charging the ESS until the ESS SOC achieves an abnormal state and the EM will assume control to move the boat. Energy management strategy (EMS) for the PHERB is expected to spare the weight, space and cost in addition to enhance the fuel economy and emission.

Modeling and simulation are the important part in development model [9]-[12]. Currently, researchers focus on understanding the progressing system of the hybrid vehicles by developing the simulators [13], [14]. The results can be used to optimize the design of hybrid vehicles before prototype

structure begins. Besides that, power flow management, optimization of the fuel economy and reducing the emissions are part of the current research [15]-[18]. Several computer programs have been developed to describe the operation of hybrid electric powertrains [19] including advanced vehicle simulator (ADVISOR) and an automotive simulation and analysis tool (AUTONOMIE) which compare with proposed recreational boat named PHERB.

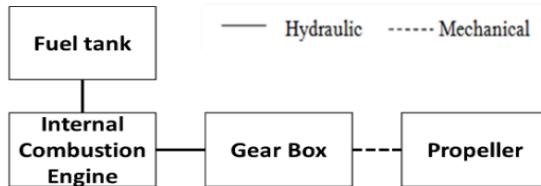


Figure 1. Block diagram of the CB powertrain

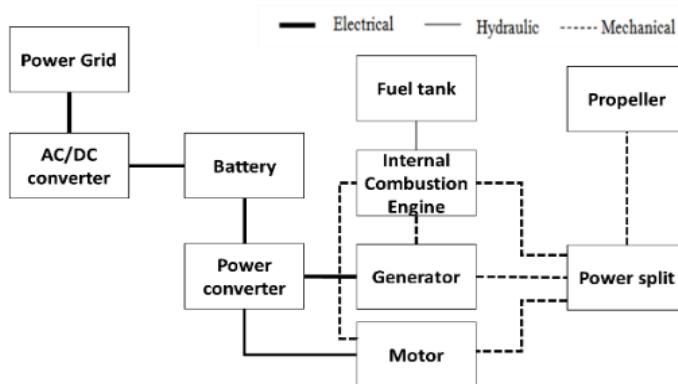


Figure 2. Block diagram of the PHEB powertrain

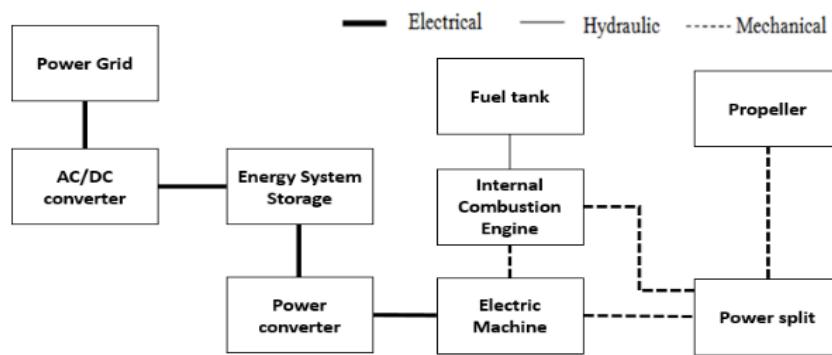


Figure 3. Block diagram of the proposed PHERB powertrain

2. METHOD

The method conducted in this research is divided by five phases which is model by software, PHERB vehicle model, and PHERB energy management system.

2.1. ADVISOR and AUTONOMIE

In this research, ADVISOR and AUTONOMIE shown in Figure 4 is the established software can be used as the reference to build the vehicle such as car, boat, bus, truck and so on. U.S. department of energy (DOE) and the national renewable energy laboratory (NREL) was developed ADVISOR as shown in Figure

4 as a software based on the MATLAB/Simulink environment used to simulate and analyze conventional, electric, hybrid electric and plug-in hybrid electric vehicle [20]-[21]. AUTONOMIE was developed by argonne national laboratory (ANL) and sponsored by the DOE. The MATLAB/Simulink environment-based simulation toolbox supports rapid vehicle powertrain modeling and analysis of various powertrain and control systems through the evaluation of vehicle's fuel economy, performance, and energy efficiency under various dynamic or transient testing conditions [22]-[23]. The ADVISOR and AUTONOMIE models have been approved and utilized as a benchmark of reference display because ADVISOR and AUTONOMIE is the established software. To mimic the PHERB, the model has determined and tried by contrasting the re-enactment results and ADVISOR and AUTONOMIE. Likewise, PHERB was produced as forward-looking vehicle simulation architecture comparable with AUTONOMIE show however ADVISOR uses in reverse looking vehicle simulation architecture.

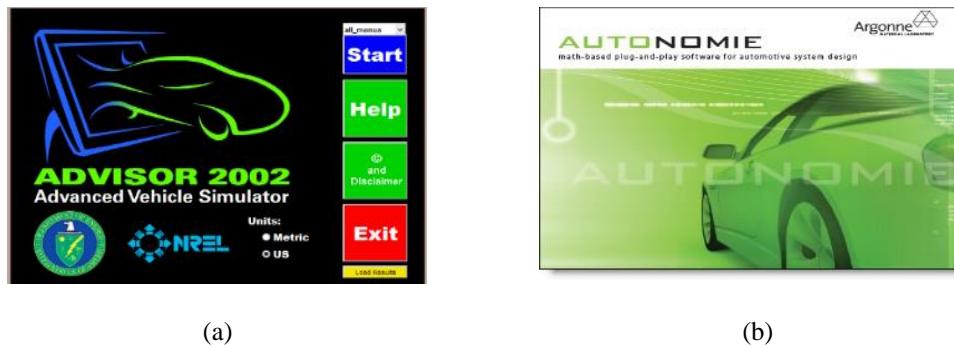


Figure 4. (a) ADVISOR and (b) AUTONOMIE software

2.2. PHERB vehicle model

Design specifications, requirements, sizing and selection for EM, ICE and energy storage system (ESS) are carried out in order to identify the main components of PHERB powertrain. The EM, ICE and ESS are sized according to boat parameter, specifications, and performance requirements as shown in Table 1, based on the boat power requirement for steady state velocity using dynamic equation boat [24]-[28]. The boat type selected is a recreational boat. In simulation, the length of boat used is 12.4 m and density of water is 1000 kgm⁻³.

The enlargement of boat model starts with the estimations of boat energy and power needed for common driving situations based on the parameters and target specifications of the boat based on PHERB specification, parameter and requirement. Through a power flow analysis, the size and limit of each component are decided accordingly to get the necessities. Table 2 displayed the size and specifications used for PHERB [29]-[34].

Table 1. PHERB parameters, specifications and performance requirements

Parameter and Specifications			
Configuration	Series-Parallel	Configuration	Series-Parallel
Length overall, L	12.4 m	Length between perpendicular, L _{PP}	10.67 m
Length at waterline, LWT	11.0 m	Density of water, ρ	1000 kgm ⁻³
Breadth, B	1.8 m	Total propulsive efficiencies, η _T	0.9
Draught, T	0.64 m	Performance Requirement	
Maximum speed	Over 30 km/h		
EV range	10 km		

Table 2. PHERB component specification

Component	Specifications
ICE	20 kW @ 3000 rpm
EM	30 kW AC induction motor
Battery	Li, 5 kWh, 6 Ah

All parts in PHERB obtain a mathematical model is combined. The boat performance is simulated in the MATLAB/Simulink environment with a special EMS and different driving cycle. Overall structure of PHERB model is illustrated in Figure 5.

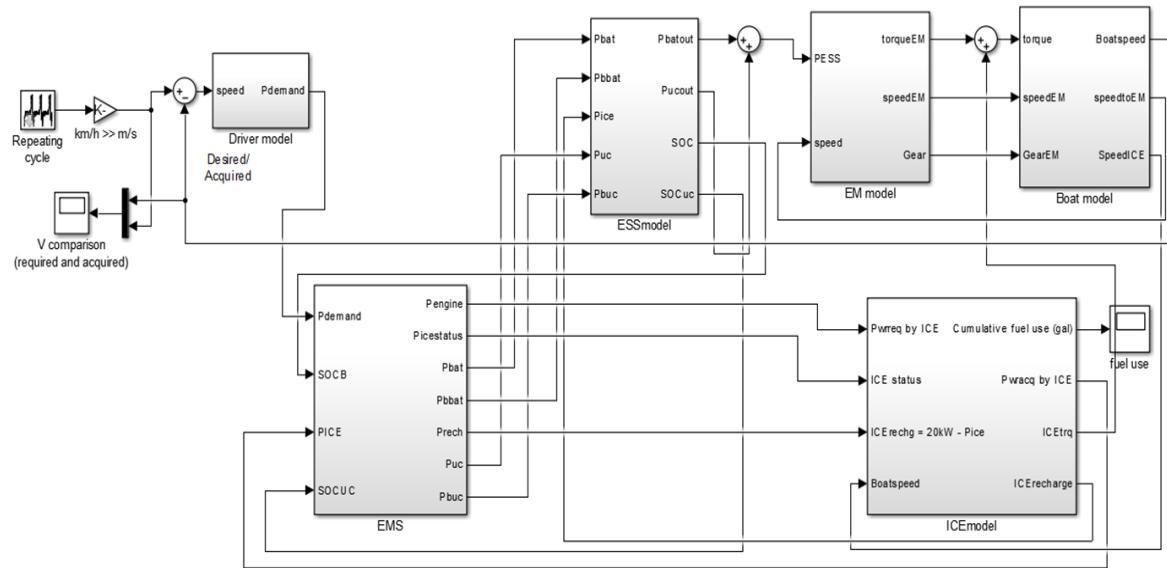


Figure 5. Overall structure of the PHERB model in MATLAB/Simulink

2.3. PHERB energy management strategy

EMS is dependable of choosing in which mode that the boat is working. A few working methods of the proposed EMS appeared in Figure 6 to control the flow of power among the ESS, EM, and ICE, including the mechanical braking, regenerative braking, motor only, engine recharge, motor and engine, and engine only mode refer to the boat demand in forward and reverse cruising and SOC level of ESS [35], [36].

The mechanical braking mode is started if the SOC of both ESS and the throttle position is high. Amid the regenerative braking mode, the distribution of absorbed regenerative power be determined by on the percentage of throttle position as well as on the SOC level of both storage units. EM only mode can be activated when the SOC level is high. When the ESS SOC and the speed are low, the ICE will drive the boat for charging the ESS. If the boat is cruising and the ESS has a moderate SOC, then the boat can be either ICE recharge or EM only mode refer to previous mode. If the boat acceleration is high, then the ICE will not have an opportunity to charge the ESS because the ICE only mode is activated.

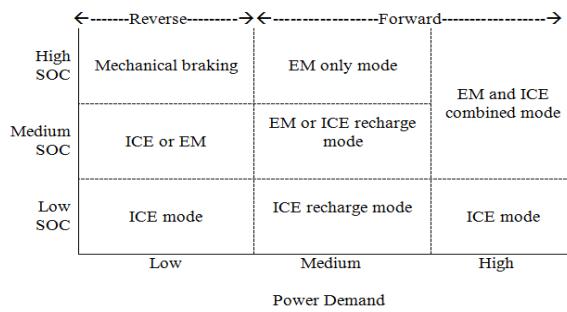


Figure 6. PHERB EMS modes of operation

3. RESULT AND DISCUSSION

This section is divided to two phases which is PHERB model verification and PHERB fuel economy and emission analysis.

3.1. PHERB model verification

For model verification, PHERB model is modified to incorporate the plug-in hybrid electric vehicle (PHEV) model and EMS. The PHERB model is verified using ADVISOR model and AUTONOMIE model.

3.1.1. Drive cycles

Two standard U.S. environmental protection agency (EPA) drive cycles: the highway fuel economy test (HWFET) and urban dynamometer driving schedule (UDDS) are simulated to verify the model of PHERB as plug-in hybrid vehicle. Figure 7 and Figure 8 illustrated the HWFET and UDDS drive cycles which is finishes at 765 seconds and 1369 seconds, respectively.

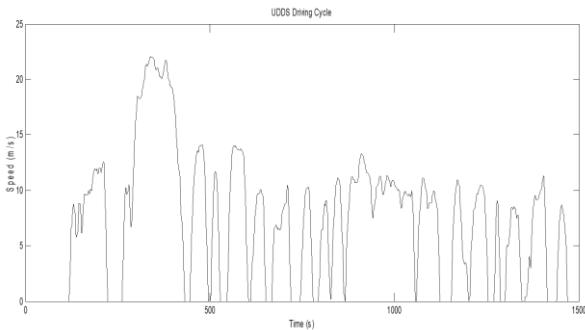


Figure 7. UDDS driving cycle

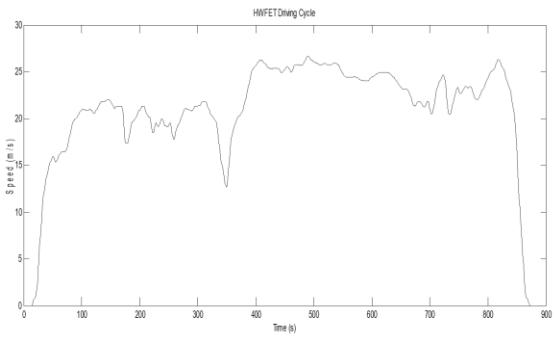


Figure 8. HWFET driving cycle

3.1.2. Boat performance

Figures 9-12 outlined the simulation regarding the boat speed and force via ADVISOR and AUTONOMIE. As appeared in Figures 9-12, the real boat force and speed of the HWFET and UDDS drive cycles reproduced by the ADVISOR or AUTONOMIE (blue lines) and the PHERB show (red lines) concur well with each other.

3.1.3. Energy system storage

From the ESS output power, voltage and current in Figures 9-12, can assume that to attain speed boat during that period, the high-power demand is due to the highest current. The regenerative braking happens when the negative value on the graph display in the cycle. For ESS voltage, when ESS recharging in the regenerative braking mode, the voltage increases and decreases when the power needed from EM is high during current peak discharge. While the two-model configuration during HWFET and the UDDS drive cycles for SOC of the battery are represented in Figures 9-12.

The whole pattern of two models and energy depletion equals sensibly well. Nevertheless, there is some difference with the battery SOC aftereffects of the PHERB demonstrate and ordinary PHEV show in the UDDS and HWFET drive cycle utilizing ADVISOR and AUTONOMIE. This is because the PHERB model has a detention more regenerative braking energy and a better EMS.

3.1.4. Electric machine

The result of ADVISOR, AUTONOMIE and PHERB in term power, speed and torque used EM using the HWFET and UDDS drive cycles are included in Figures 9-12. So that, when the boat accelerates, the required EM torque increments rapidly, and when the boat achieves the moderately stable interstate speed level, a smaller torque is required to beat the resistance and air drag to the boat. The speed, torque and power results from the two model compare sensibly fit.

3.1.5. Propeller

Figures 11 and 12 delineates the wheel torque and speed necessity for the HWFET drive cycle of the two models 600Nm happens when the boat is accelerating from stop to the acceleration. The needed torque at that point lessens since the HWFET drive cycle just comprises of gentle increasing velocities and decelerations. The general outcomes and patterns coordinate intently. Figures 9 and 10 demonstrates the haggle required amid the UDDS drive cycle and the outcomes from ADVISOR, AUTONOMIE and PHERB show coordinate exceptionally well.

3.1.6. Acquired and required speed

Figures 9-12 show that the acquired and required speed concur sensibly well. The PHERB model followed the desired drive cycle speed very well for both standard drive cycles match with ADVISOR and AUTONOMIE.

In combination with the previous discussion, it can be concluded that the results of the components of the vehicle subsystems of PHERB model are correctly sized as the boat is capable of achieving performance to a target velocity.

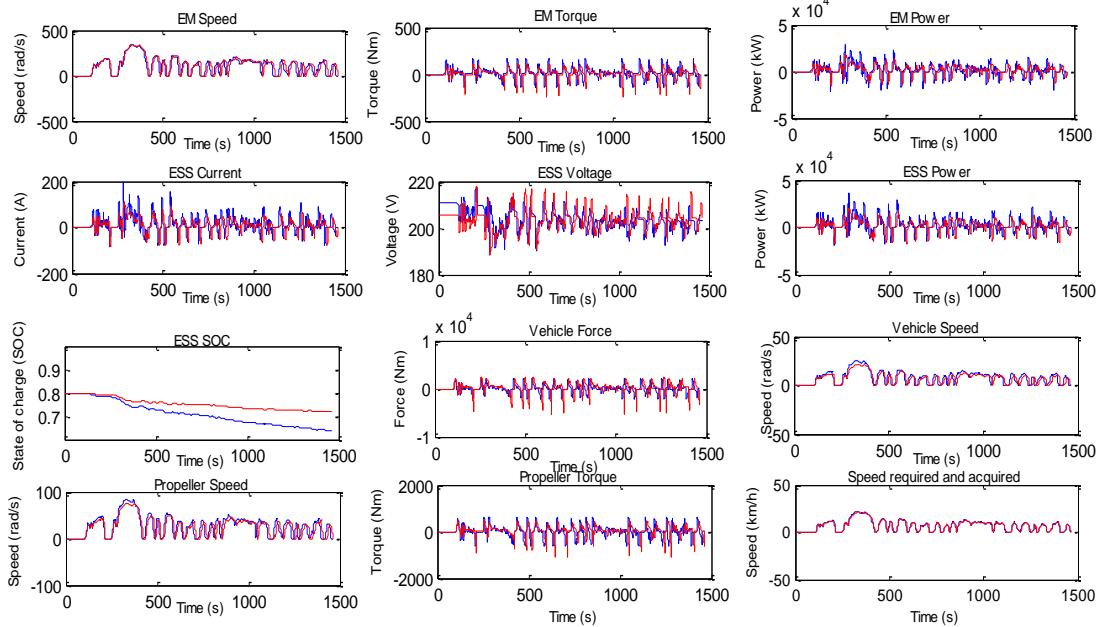


Figure 9. Simulation results of UDDS driving cycle using AUTONOMIE (Blue: ADVISOR, Red: PHERB)

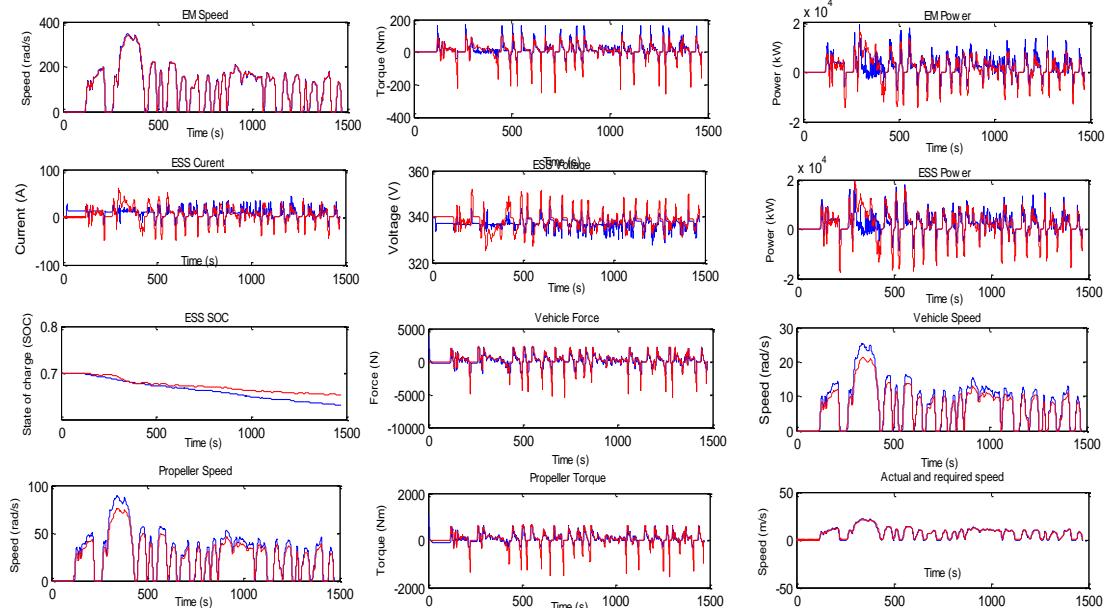


Figure 10. Simulation results of UDDS driving cycle using ADVISOR (Blue: ADVISOR, Red: PHERB)

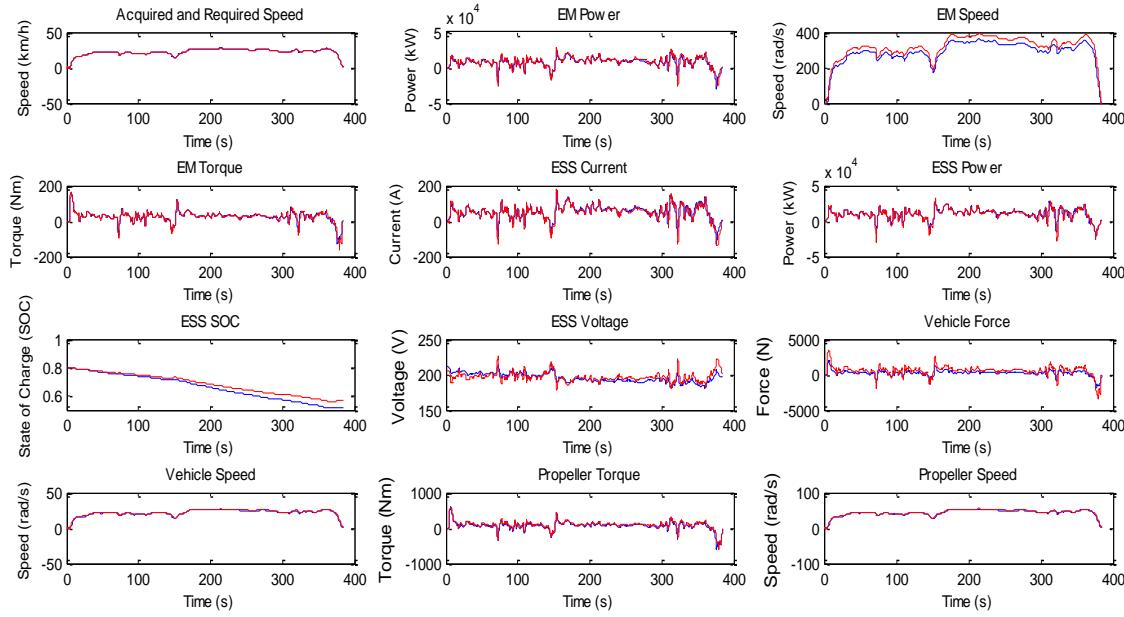


Figure 11. Simulation results of HWFET driving cycle using AUTONOMIE (Blue: ADVISOR, Red: PHERB)

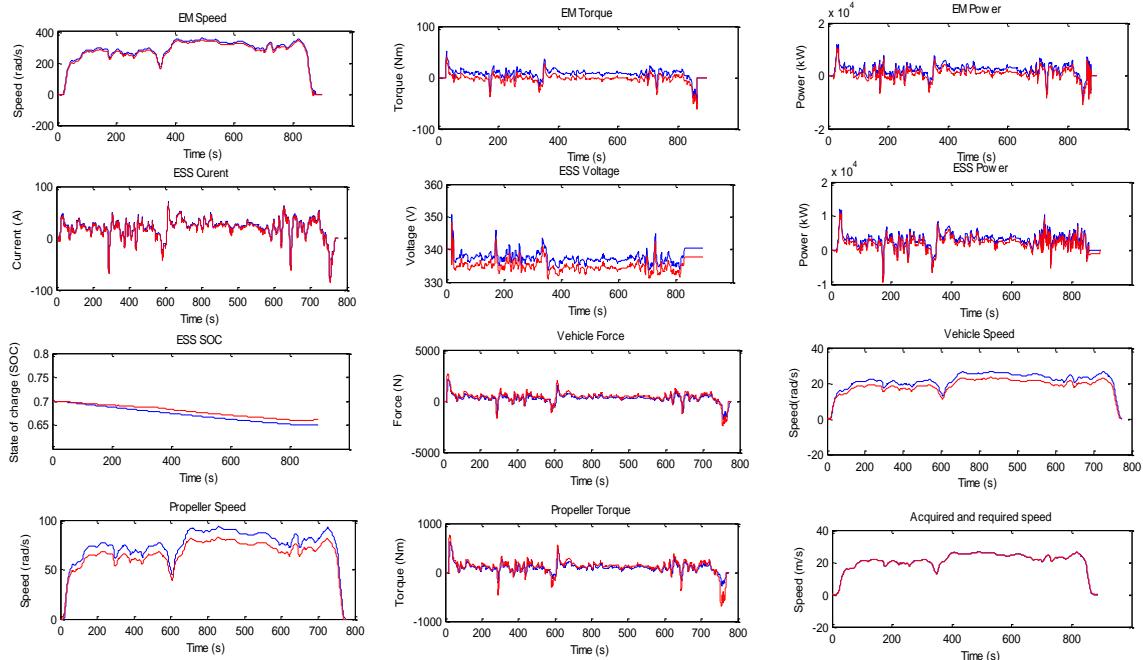


Figure 12. Simulation results of HWFET driving cycle using ADVISOR (Blue: ADVISOR, Red: PHERB)

3.2. Pherb fuel economy and emission analysis

This analysis compared the fuel economy (FE) and emissions shown in Tables 2-3 which is hydrocarbon (HC), carbon-monoxide (CO), nitrogen-dioxide (NO_x) and carbon dioxide (CO₂) using PHERB, ADVISOR and AUTONOMIE, for the HWFET driving cycle, UDDS driving cycle and a few water drive cycles. The water driving cycle used are Kuala Terengganu (KT), Seberang Takir (ST), Kampung Laut (KL), Tasik Kenyir (TK), and Pulau Kapas (PK) presented in Figure 13. The FE and FE improvement can be determined using (1) and (2) (37-39) where D is distance in miles and V_{fuel} is volume of fuel in consumed in gallons.

$$FE (\text{mpg}) = \frac{D}{V_{fuel}} \quad (1)$$

$$\text{Percentage of FE improvement} = \frac{\text{Before}-\text{After}}{\text{Before}} \times 100\% \quad (2)$$

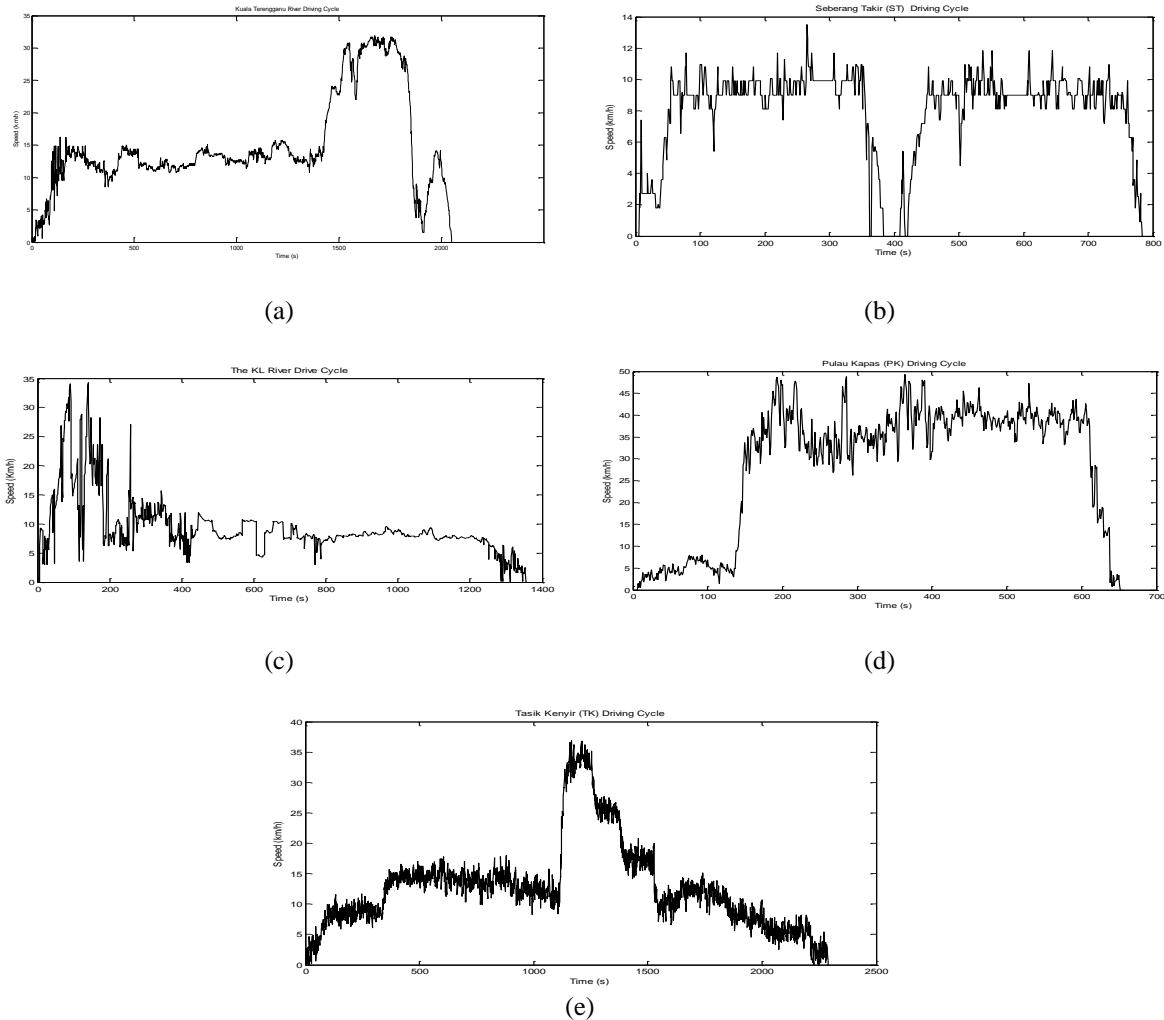


Figure 13. Water driving cycle used, (a) KT driving cycle, (b) ST driving cycle, (c) KL driving cycle, (d) PK driving cycle, (e) TK driving cycle

The different pattern of driving cycle and models were given the different value of FE and emission. The FE and emission of PHERB, ADVISOR and AUTONOMIE model are listed in Tables 2-3 is analysed using model analysis in MATLAB/Simulink environment.

From the Tables 2-3, a significant improvement in the fuel economy and emissions were achieved by the PHERB model. Based on the analysis results, the following observations can be made. The FE of the PHERB is about 33% higher than that of the ADVISOR model, 13% higher than the AUTONOMIE model for the KT drive cycle. For ST driving cycle, the FE of PHERB is 36% higher than that of the ADVISOR model and 15% higher than the AUTONOMIE model. Hence, for KL, TK and PK driving cycles show the increasing in FE of PHERB such as 42%, 77%, and 20% than ADVISOR model and 14%, 18%, 11% higher compared to AUTONOMIE model. Besides that, the FE of the PHERB for UDDS and HWFET driving cycle presented 17% and 10% for ADVISOR model, while for AUTONOMIE model, PHERB was improved about 8% and 7% respectively.

In emission studied, PHERB and ADVISOR model show the result of three type emission such as HC, CO, and NOx. The results displayed PHERB model has a lower emission compared to ADVISOR

model. It differences for AUTONOMIE, AUTONOMIE model only given the result for CO₂ emission. This happens because ESS model in PHERB model have battery and UC bank but in ADVISOR and AUTONOMIE model has only the battery in the ESS. UC be the important role to improve the FE and emissions. Besides that, a special EMS is used in PHERB model that can increase the FE and reduced the emission.

Table 2. Fuel economy and emission using ADVISOR and AUTONOMIE

Driving Cycle	Fuel Economy (mpg)	ADVISOR				AUTONOMIE				
		HC	CO	NOx	CO ₂	Fuel Economy (mpg)	HC	CO	NOx	CO ₂
KT	73.5	0.462	0.492	0.107	-	95.5	-	-	-	42.171
ST	43.0	1.757	1.734	0.121	-	56.8	-	-	-	21.097
KL	41.9	1.018	1.319	0.340	-	62.5	-	-	-	46.080
TK	40.7	0.565	0.587	0.175	-	145.5	-	-	-	112.045
PK	35.0	0.684	0.859	0.274	-	38.8	-	-	-	155.416
UDDS	62.3	0.561	0.743	0.195	-	68.9	-	-	-	18.980
HWFET	87.6	0.394	0.602	0.183	-	90.4	-	-	-	22.910

Table 3. Fuel economy and emission using PHERB

Driving Cycle	Fuel Economy (mpg)	PHERB		
		HC	Emission (g/m)	CO ₂
		CO	NOx	
KT	109.8	0.547	0.279	0.000
ST	66.7	1.046	0.534	0.000
KL	72.6	0.878	0.448	0.000
TK	178.0	0.711	0.474	0.057
PK	43.7	0.296	0.151	0.000
UDDS	74.7	0.415	0.215	0.000
HWFET	97.3	0.224	0.203	0.047

4. CONCLUSION

The boat subsystems in terms of ESS current, voltage, output power and SOC, EM speed and torque, boat speed and force and propeller speed and torque are within reasonable and expected range of actual typical behavior of these subsystems. The components of the boat subsystems are correctly sized as the vehicle can achieve performance to a target velocity. The fuel economy and emissions for the driving cycle used shown similarity based on software used because ADVISOR and AUTONOMIE have different characteristic and focused on different part in modelling and simulation. It can be concluded that results of the PHERB model are the most precise compared to ADVISOR and AUTONOMIE. So that, it can be used as reference to build the prototype of hybrid electric recreational boat in Malaysia environment.

ACKNOWLEDGEMENTS

The authors would like to be obliged to Universiti Malaysia Terengganu (UMT) for UMT Scholarship, Ministry of Education Malaysia for providing financial assistance under FRGS (59353) grant and Faculty of Ocean Engineering Technology and Informatics, UMT for all their technical and research support for this work to be successfully complete.

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